EFFECT OF YARN AND FABRIC STRUCTURE ON AIR PERMEABILITY

Dr. W. Hamburger
Fabric Research Laboratories, Inc.
Boston, Massachusetts

Introduction

Permeability is the dominant functional characteristic of parachute cloth. Excessive permeability reduces deceleration rates, while too low a permeability can cause excessive loads on both the chute and the object being decelerated. High speed objects and attendent high pressure drops on chutes have necessitated the development of more rational understanding of the factors affecting permeability.

The problem is very complex because of:

(a) Variety of types, and thus their effects, of geometrical factors, (plain weave cloth alone, ideally, has 11 variables of construction, add to this the effects of yarn structure).

(b) The type of flow through fabrics can and does change from "simple stream-line" flow to turbulent flow at high pressure drops.

(c) The nature of the "orifice" in fabric flow changes with pressure drop i. e., crimp interchange under biaxial tension enlarges the fabric "pores" and can increase the flow between yarns, while increases in turbulence and flow between fibers can assume importance at high pressure drops.

These complexities are enough to make precise dynamic analyses impossible, and point the way for intelligent empiricism which, after all, is also resorted to in determining discharge coefficients of various "classical orifices" in fluid flow over wide ranges of Reynolds numbers. Notwithstanding such complexities, it is possible to predict the trend of results over broad ranges of yarn and fabric structure by taking the most simplified point of view, namely, the flow through orifices defined by the projected pore area, and assuming the flow to be proportional to such area.

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Analysis of Factors Affecting Projected Pore Area

By simple geometry, it is possible to show that ρ , the proportion of fabric area which would appear open in projected plan view of the fabric, may be deduced as :

$$(1) \qquad \rho = \left[1 - (d_w)_h \; T_w \quad 1 - (d_f)_h \; T_f \right]$$

where :

$(d_w)_h$ and $(d_f)_h$ are the horizontal diameters, that is, in the plane of the fabric, of warp and filling yarns, respectively.

T_w and T_f are, respectively, the warp and filling threads per inch. Assuming flow to be proportional to the projected porosity ρ , then it is possible to make several speculations regarding extent to flow which, surprisingly, correlate with test results at least in trend :

A.) Effects of Cover Factor

By Cover Factor is meant the quantities (d)T appearing in Equation 1. Assuming, for the moment circular x-section yarns, then fabric weight per unit area, W_t, neglecting the small effect of yarn crimp can be shown to be :

$$(2) \qquad W_t = K \left[T_W \frac{\pi d_w^2}{4} \right] \gamma_w + T_f \left[\frac{\pi d_f^2}{4} \right] \gamma_f$$

where γ_w and γ_f are the bulk densities of warp and filling yarns, respectively, and K is a proportionality factor for dimensional units. Assuming, for simplification, that $d_w = d_f$, $T_w = T_f$ and $\gamma_w = \gamma_f$, then combination of Equations (1) and (2) result in:

$$(3) \qquad \rho = \left[1 - \frac{2 W_t}{K \pi \gamma d} \right]^2$$

Thus, if fabric weight, W_t, is held constant, porosity may be deduced by increase in cover factor, obtained by decrease in either γ , the yarn density, or in d, the yarn diameter. In the case of yarn diameter decrease, constant weight would require the use of more fine threads, and it is well known from experience that permeability decreases with use of a greater number of finer threads holding weight constant. Obviously, if fabric weight is increased for a given yarn size and density, permeability will decrease, but it is also true that if weight is increased by incorrectly varying both yarn size, and fabric texture, permeability may increase. Correspondingly, it is possible to decrease fabric weight and also permeability by the proper selection of changes in yarn size and fabric texture, always in the direction of using more fine threads.

B.) Effects of Yarn Flattening

In a more general case, the yarns are not circular, their departure from circularity increasing with decrease in yarn twist. Under these conditions, Equation (3) would be replaced by:

$$(4) \qquad \rho = \left[1 - \frac{2W_t}{K\pi\gamma(d_v)}\right]^2$$

where d_v is the vertical yarn diameter. Obviously, if constant fabric weight is maintained, the smaller d_v, the smaller the porosity. Thus, yarn flattening is of great importance. If yarn area (yarn weight) is maintained constant, the greater the degree of flattening the smaller d_v, and the less the permeability. Flattening, which can be achieved by either twist reduction or fabric calendering, can have a tremendous effect, particularly at medium or high cover factors where a small change in absolute projected pore area can cause a large percentage change in fabric porosity. On a series of cellulose acetate fabrics of 300 denier yarns, the following effects of yarn twist on fabric permeability of a 1/1 plain weave fabric were observed.

	Values of Permeability @0.5" water for (T_w + T_f) of:			
Yarn Twist, TPI	90	100	110	120
0.3 (Filament)	45	20	10	8
6.0 (Filament)	350	185	115	65
11.0 (Staple)	370	260	190	125
12.0 (Filament)	---*	---	270	175
19.0 (Staple)	590	400	290	200
24.0 (Filament)	---	---	700	(no fabric available)
27.0 (Staple)	---	550	380	265

*Blanks mean samples too permeable for readings.

It can be seen from the above, that at equal fabric weights (equal values of T_w + T_f), decreases in twist produce very large decreases in permeability, in most cases a greater decrease than that produced by increases in fabric weight. The inversions in the above table of the twist effect were due to changes in both yarn flattening and yarn density of the staple versus the filamentous yarns. For example, the 24 TPI filament yarn was both rounder and more dense than the 27 TPI staple yarn.

The same effects of similar twist variations over the same range of fabric weights were observed for both 2/2 basket and 3/1 twill weaves as are shown by the above results for plain weaves. While both the 2/2 basket and 3/1 twill weaves have approximately the same permeability, they do manifest greater permeability than do their plain weave counterparts (particularly at high cover factors). In large measure, this appears to be the result of decreased yarn flattening for such weaves, occasioned by the decreased pressure at yarn cross-overs in the weaving operation. However, some of the differences are doubtlessly the result of differences in pore shapes, as defined by Backer, and as briefly described later.

It is interesting to note that the increased yarn compaction resulting from twist increases did not reduce the flow. If any significant part of the total flow took place between the fibers, it would be anticipated that twist increases would decrease the flow. The marked increase observed in flow with twist increase would thus indicate inter-fiber flow to be negligible at low pressure drops. It remains for future work to ascertain whether this is also true at high pressure drops. Thus far, the data obtained under our WADC project on permeability does not indicate decreased flow with increase in yarn twist even at pressure drops of 50 inches of water tending to confirm the hypothesis of negligible magnitude of flow between fibers.

C.) Effects of Fabric Weave

The assumption that projected pore area controls flow would appear to have theoretical validity only for very open fabrics, i.e., where the sets of threads which bound any one pore are small in width relative to the pore dimensions. One would anticipate that as the thread spacing is decreased, the type of thread crossing would have significant effect on the flow. Backer has analyzed types of thread crossing from the point of view of indicating differences between projected pore areas and actual minimum pore areas. These latter were determined by mechanically computing the open areas, in the plane of the fabric, found by sectioning fabrics at different elevations through the pores. While a complete solution of the problem would require similar analyses for each set of fabric dimensions and degree of crimp balance of interest, Backer's work was limited to a particular cover factor fabric, with balance of all warp and filling structural factors. Nevertheless, an effect was shown wherein the plain weave fabric gave the lowest minimum pore area. Actual minimum pore area was shown to be a function of weave with weave classified by the number of each type of crossing of the four threads which bound each pore, per repeat of the fabric. It was found convenient to classify pore types as follows:

Type A - All four bounding threads having equal crimp greater than zero.

Type B - One warp and one filling thread having equal crimp. The remaining warp and filling thread have zero crimp.

Type C - All four threads having zero crimp, with the two filling (or warp) threads displaced.

Type D - All four threads having zero crimp, with no thread displacements.

The zero crimp condition applies only to those portions of the threads which form the pore boundaries. A plain weave is composed entirely of Type A pores, while other weaves show varying amounts of each type in a single repeat of the weave pattern. Each type of pore gives a different actual minimum pore area, and the weighted minima were used by Backer to describe relative porosities of fabrics of different weaves. In general, observed results, particularly for high cover factor fabrics, do correlate somewhat better with weighted minimum actual pore area than with projected pore area, and thus some of the effects of weave type can be predicted. It is felt that differences in yarn flattening produced by weave differences may be responsible for at least some of the otherwise unaccounted for discrepancies.

D.) Effects of Pressure Drop

The subject of the magnitude of pressure drop and its effects on permeability is the work currently being studied at Fabric Research Laboratories, Inc., on its WADC research, and the results of this study have not yet been fully analyzed. Nevertheless, it appears that the following factors must be considered.

1. To what extent does the degree of yarn flattening existent at low pressure drops remain in effect at high pressure drops? The magnitude of the yarn tensions created by high pressure differentials can cause recircularization of yarns where they are free of cross-thread contact but increased flattening due to high normal pressures at yarn cross-overs. The extent of increased flattening would not appear to be large, particularly if the fabrics were woven under high tensions.

2. Under the biaxial tensions created as a result of increased pressure drop, is there an opportunity for crimp interchange to increase the pore area, either projected or minimum? If the pore area increases even a slight amount, the permeability of tight fabrics

may be greatly increased over and above that which would normally take place for the increased pressure drops. Attempts have been made to apply the formulae of Hoerner to predict the rate of increase in flow with increase in pressure drop for several of the fabrics being investigated on our WADC project. In the cases thus far analyzed, experimental results agree reasonably well with those computed from Hoerner's formulae, taking into account only the increase Reynolds number at the higher pressure drops. The discrepancies between experimental and computed rates of flow appear to reside in the assumption of constant pore area at all pressure differentials. Experimental permeabilities are of greater magnitude than computed permeabilities, the differences increasing as the pressure drop increases. While some of the increase may be the result of flow between fibers at high pressure drops, it is also probable that the increases in pore area resulting from fabric deformation under the biaxial tension developed by the high pressure differentials could be the cause of the differences. In addition, the effect of diminished fabric thickness may decrease the total friction of moving air against fabric and hence increase the flow. The effect of fabric thickness is at present obscure, but it probably does play an important part in explaining some of the effects of high pressure drop.

Several slides have been prepared to illustrate the combined effects of yarn twist and magnitude of pressure drop on air permeability. These represent a portion of the data being obtained under our present contract. These slides will show that, in general, twist and calendering produce the same effects on permeability at high pressure drops as at low pressure drops. However, the magnitude of the effects of twist seems to be dependent on the magnitude of the pressure drop, not a surprising result in view of the many complex interactions alluded to herein.

Obviously, there are undoubtedly many more questions for which answers will have to be found, particularly on the combined effects of both yarn and fabric structure, including thickness and increased pressure drop. It is hoped that this project will help furnish the answers to these questions.